Absolute Sensitivity Measurement for the Thermal Ion Dynamics Experiment

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Space plasma can be described to a surprisingly adequate extent for many purposes by simply specifying the moments of the velocity distribution function, $f(v)$. For this to be accomplished, the instrument's geometric factor, or absolute sensitivity, has to be measured before flight. With the knowledge of the instrument's raw count rate in a certain state and the energy-dependent geometric factor, information about the plasma can be obtained by calculating the density, velocity, and temperature.

Previous experience shows, however, that the range of geometric factors previously considered adequate are actually inadequate when a space plasma instrument is carried into regions of very low plasma density. Also, positive floating potentials of spacecraft exposed to sunlight and low density plasmas make low energy plasma observations all but impossible by excluding low energy ions from the spacecraft, exacerbating the sensitivity problem.[2] Resulting from these circumstances, a fundamental design goal of the Thermal Ion Dynamics Experiment has been to achieve a geometric factor much greater than that of previous instruments.

The Thermal Ion Dynamics Experiment is a space plasma flight instrument that will be carried on the POLAR spacecraft for the Global Geospace Mission, and was developed to make three-dimensional plasma composition measurements capable of tracking the circulation of low energy (0 to 500 electron volts) ions through the polar magnetosphere.[2] Its final testing and calibration before flight was conducted early this summer in the Low Energy Electron and Ion Facility, with one of the main objectives being to measure the geometric factor of the instrument.

The Thermal Ion Dynamics Experiment

The Thermal Ion Dynamics Experiment will provide low energy measurements that are differential in energy and direction as well as mass, with range and resolution adequate for the full characterization of velocity distribution features known to exist in the low energy plasma populations.[2] Two of its design characteristics, its methods of energy and mass analysis, allow for a large geometric factor necessary to obtain these velocity distributions.

To be detected, ions will enter one of seven polar angle apertures and pass through a collimator, an energy analyzer, and then a mass analyzer. An electrostatic mirror combined with a retarding potential analyzer provides the differential energy analysis. Ions that are too energetic pass through the mirror and are lost, while those of insufficient energy are reflected by the retarding potential analyzer. This electrostatic element combination forms the energy bandpass, which can be adjusted in width by selection of the potential bias ratios. The mirror, which plays a major role in the achievement of the large Thermal Ion Dynamics Experiment geometric factor, is of a quasiparabolic shape and translates a large collection area and small solid angle to a small collection area/large solid angle at the entrance to the mass analysis section.[2]

Coupled with each energy analyzer system is a time-of-flight system for mass analysis. After the ions exit the energy analyzer section, they are accelerated through an ultraviolet rejection section and then pass through a carbon foil, where a secondary election is collected at a microchannel plate, initiating the "start" pulse. The ions continue through the time-of-flight region and arrive at a microchannel plate where the "stop" pulse is generated. The delay between the start and stop signals is inversely proportional to the velocity at a known energy/charge and can be converted to a mass/charge. Unlike other magnetic mass analysis systems, the time-of-flight technique permits the use of a large entrance aperture, since no object slit is required to form a mass spectrum image. The large pre-acceleration potential also allows usage of a very large angular acceptance aperture, so that very large geometric factors become possible.[2]

Low-Energy Electron and Ion Facility

The instrument's geometric factor and other response characteristics were tested and calibrated in the Low Energy Electron and Ion Facility. This laboratory system, which has been used for several flight programs, was designed for testing and calibration of low energy particle detectors over a range of particle energy, mass, flux, and angular acceptance. It features a large vacuum chamber, a patented ion source designed to produce low energy ion beams with a large area, beam-imaging diagnostics, and a rotation table that enables motor-driven positioning of the instrument relative to the particle beam. The flight instrument can be placed on the turntable fixture so that the instrument can be tilted ±90 degrees and rotated ±180 degrees relative to the ion source. National Instrument's data acquisition and control software, LabVIEW, was used to link the computers and control the laboratory devices to make efficient use of a flight instrument's testing and calibration time.

Calculating and Measuring the Absolute Sensitivity of an Instrument

The geometric factor is the relation between the number of particles, *C* (particles/second), transmitted by the instrument in a known sensitive state and the differential directional flux, or intensity, at the instrument aperture, *j*, (particles per square centimeter per second per electron volt per steradian).

$$C = G * j$$

The symbol for the geometric factor in this relation is *G*, and it is the product of the integral factors, dA, $d\Omega$, and dE. The effective area, dA, is the measure of the effective area that the instrument presents to the exterior environment; $d\Omega$ is the effective solid angle response width; and dE is the effective energy response width. To make this measurement in the laboratory, it is important to expose the instrument to a monoenergetic and unidirectional beam of known intensity and purified composition.

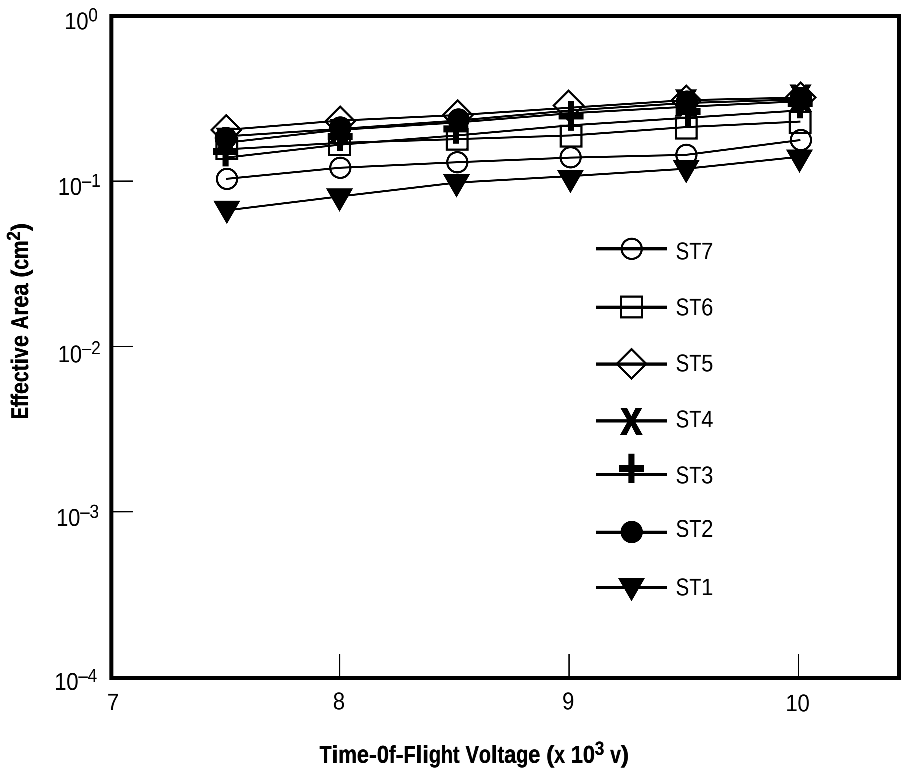

FIGURE 35.—Thermal Ion Dynamics Experiment final calibration: June 16, 1995. Sensitivity to ions derived from an H_2 bleed.

The effective area (fig. 35) is shown for the seven "start" signals as a function of the instrument's time-of-flight voltage. These numbers multiplied by the energy response width and the solid angle response width will give the geometric factor of the instrument. During calibration, the Thermal Ion Dynamics Experiment geometric factor was measured to be at least 10 times larger than previous flight instrument testings in our laboratory.

Biddle, A.P., and Reynolds, J.M. 1985. An Integrated Development Facility for the Calibration of Low Energy Charge Particle Flight Instrumentation.

The Thermal Ion Dynamics Experiment and Plasma Source Instrument. 1995. *Space Science Reviews*, 71:408–58.